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UNITED STATES PATENT APPLICATION

for

SENSOR AND METHOD FOR DETECTING A PATIENT'S MOVEMENT VIA POSITION AND OCCLUSION

by

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SENSOR AND METHOD FOR DETECTING A PATIENT'S MOVEMENT VIA POSITION AND OCCLUSION

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application serial number 60/487,021 filed on July 14, 2003.

FIELD OF THE INVENTION

[0002] This invention relates generally to monitoring systems and more particularly concerns devices and systems used to monitor seated or lying patients in homes or in medical environments such as hospitals, institutions, and other care-giving environments so as to reduce the risk that such patients will develop decubitus ulcers.

BACKGROUND OF THE INVENTION

[0003] It is well known that patients who are confined to a bed or chair for extended periods of time are at risk of developing decubitus ulcers, i.e., pressure sores, or bed sores as they are more commonly known. These ulcers are often seen to develop within soft tissue that is compressed between a bed or chair surface and a patient's weight-bearing bony prominences, the compressed tissue being at least partially of deprived of oxygenated blood flow. A continued lack of blood flow, and resultant lack of oxygen, can result in cell death, which may be evidenced in the form of pressure sores. Pressure sores do not develop immediately, but rather form over time, with the development speed depending on a number of factors including the firmness and friction of the supporting

surface against the patient's skin, the patient/ambient temperature, the amount of moisture in contact with the skin, and the health and susceptibility of the skin due to age, illness, and/or nutrition.

[0004] One venerable and generally accepted means of reducing the risk of decubitus ulcer development in bedfast patients is to turn them regularly, usually at approximately two hour intervals. For example, a patient in a back rest position might be periodically rolled to one side or the other, such motion helping to maintain blood flow to soft tissue that is under compression. Similar strategies are employed for patients that are confined to a chair for long periods of time. Obviously, an assisted-movement strategy relies largely on the vigilance of the (often harried) attending staff to insure that the patient is properly relocated. Further, it is far too easy for the busy caregiver to let the time for turning the patient slip by in the press of other daily emergencies. To the extent that the caregiver is too busy or forgets to perform this service, this method can fail to achieve its purpose. Further, this sort of strategy can be counterproductive for use with the patient that has some capacity for self-movement when, for example, the patient may have turned himself just before the caregiver arrived to manually turn him, in which case the caregiver will likely place the patient back in the position from which he recently moved, thus inadvertently exacerbating the problem. Further, after being rolled to a new position the patient might return to the original "comfortable" position after the caregiver leaves which would obviously negate the effects of the reposition.

[0005] The process of moving a patient to another position is admittedly disruptive to the patient and this is especially true at night, since the patient — if he or she were sleeping — will be awakened for the purpose of relocation. The typical two-hour

movement interval must be observed around the clock if the method is to be effective, so it is necessary to disturb the patient — who might be sleeping soundly at the time — to make the required adjustment in position. Further, this adjustment might not have even been necessary, or even counter indicated, if the patient had recently moved of his or her own volition. Thus, in many situations it would be advantageous for the caregiver to know if and when the patient last moved his or herself. Then, if the last movement were within a prescribed period of time, it might be possible to spare the patient an unnecessary interruption in his or her healing sleep. The caregiver would then relocate the sleeping patient, only if that relocation were actually required. Further, knowing which patients do *not* need to be moved could result in a substantial savings in labor costs, as the time that would otherwise be devoted to moving the patient that did not actually need to be moved could be productively applied elsewhere. That being said, as useful as this sort of information might be to the health care provider, however, the present state-of-the-art in patient management does not provide this sort information.

[0006] Generally speaking, there are two broad approaches to dealing with decubitus ulcers: mechanical and medicinal. The medical approach is concerned with the development of medicinal compounds and methods for treating the ulcer after it occurs. This approach is obviously quite useful but ultimately it is reactive, rather than proactive, because it attempts to minimize the damage occasioned by the ulcer after it has formed.

[0007] On the other hand, the mechanical approach typically utilizes a specialized mattress, pad, or other arrangement, which is designed to lessen the weight-pressure that is brought to bear on the patient's bony prominences. These devices might be either static (e.g., foam, air, or water mattresses) or dynamic (e.g., compartmentally inflatable

mattresses that dynamically shift the locus of support pressure under the patient over time. Examples of inventions in the prior art that are generally concerned with this subject matter include U.S. Letters Patent 4,425,676, 5,926,884, and 5,072,468, the disclosures of which are incorporated herein by reference. Generally speaking, a mechanical approach is to be preferred because it seeks to spare the patient the discomfort and risk associated with bed sores and reduces the costs associated with treating such, which costs can potentially accrue to the facility under some circumstances.

[0008] One enhanced variant of the mechanical approach utilizes a proactive strategy that seeks to avoid tissue death by using a combination of automatic monitoring of the patient's movement together with notification of a caregiver if the patient's movement pattern does not meet or exceed some predetermined level. Upon receipt of such notice, the caregiver will then manually turn the patient, as has been the custom heretofore. This approach, if properly implemented, has the potential to dramatically reduce the risk of pressure sores while keeping the cost of such preventative measures within the reach of small institutions and individual patients.

[0009] It is this last approach, electronic patient monitoring combined with caregiver intervention, which has been adopted by the instant inventors. As such, general information relating to mat-type sensors and electronic monitors for use in patient monitoring is relevant to the instant disclosure and may be found in U.S. Letters Patent Nos. 4,179,692, 4,295,133, 4,700,180, 5,600,108, 5,633,627, 5,640,145, 5,654,694, and 6,111,509 (the last of which concerns electronic monitors generally). Additional information may be found in U.S. Letters Patent Nos. 4,484,043, 4,565,910, 5,554,835, 5,623,760, 6,417,777 (sensor patents) and U.S. Letters Patent 5,065,727 (holsters for

electronic monitors), the disclosures of all of which patents are all incorporated herein by reference. Further, U.S. Letters Patent numbers 6,307,476 (discussing a sensing device which contains a validation circuit incorporated therein), U.S. patent number 6,544,200, (for automatically configured electronic monitor alarm parameters), and U.S. patent serial numbers 09/878,088 (for a binary switch and a method of its manufacture), and 10/125,059 (for a lighted splash guard) are similarly incorporated herein by reference.

[0010] Additionally, sensors other than mat-type pressure sensing switches may be used in patient monitoring including, without limitation, temperature sensors, patient activity sensors, toilet seat sensors (see, e.g., U.S. Patent No. 5,945,914), wetness sensors (e.g., U.S. Patent No. 6,292,102), decubitus ulcer sensors (e.g., U.S. Patent 6,646,556), etc., all of which are incorporated herein by reference. Thus, in the text that follows the terms "mat" or "patient sensor" should be interpreted in its broadest sense to apply to any sort of patient monitoring switch or device, whether the sensor is pressure sensitive or not.

[0011] Finally, pending U.S. Patent Application Serial No. 10 / 397,126, also incorporated herein by reference, discusses how white noise can be used in the context of decubitus ulcer prevention.

[0012] Heretofore, as is well known in the patient monitoring and, more particularly, the decubitus ulcer prevention arts, there has been a need for an invention to address and solve the above-described problems. Accordingly, it should now be recognized, as was recognized by the present inventors, that there exists, and has existed for some time, a very real need for a system for monitoring patients that would address and solve the above-described problems.

[0013] Before proceeding to a description of the present invention, however, it should be noted and remembered that the description of the invention which follows, together with the accompanying drawings, should not be construed as limiting the invention to the examples (or preferred embodiments) shown and described. This is so because those skilled in the art to which the invention pertains will be able to devise other forms of this invention within the ambit of the appended claims.

SUMMARY OF THE INVENTION

[0014] In accordance with a first aspect of the instant invention, there is provided a patient sensor and electronic monitor combination that continuously monitors a bedfast or chair bound patient to determine whether or not that patient's amount of movement is sufficient to, for example, eliminate the next scheduled turning by the caregiver.

[0015] In a first preferred arrangement of the instant invention, there is provided a sensor for use in connection with an electronic patient monitor, wherein the sensor uses a resistive ladder with spaced-apart resistors as a means of determining at least approximately a location of the patient on the sensor as well as an approximate length of the sensor which is contacted by the patient. By continuously determining both of these quantities over time it is possible to track the patient's movement and determine to what extent the patient needs to be manually turned and/or the extent to which a next-scheduled turn can be skipped. In one preferred embodiment, the resistors will be linearly spaced apart within the patient sensor.

[0016] According to another preferred arrangement, a plurality of resistive ladders arranged in a parallel configuration, one above the other, will be used to determine the position and contact region of a patient with these multiple sensors and, additionally, will be used to calculate some relative value of the shear which is being experienced by the patient as his or her body slides down in the bed. Preferably, the resistive elements will be linearly spaced apart.

[0017] The foregoing has outlined in broad terms the more important features of the invention disclosed herein so that the detailed description that follows may be more clearly understood, and so that the contribution of the instant inventor to the art may be

better appreciated. The instant invention is not to be limited in its application to the details of the construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. Rather, the invention is capable of other embodiments and of being practiced and carried out in various other ways not specifically enumerated herein. Further, the disclosure that follows is intended to apply to all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims. Finally, it should be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting, unless the specification specifically so limits the invention.

[0018] While the instant invention will be described in connection with a preferred embodiment, it will be understood that it is not intended to limit the invention to that embodiment. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings in which:

[0020] Figure **1** illustrates the general environment of the instant invention, wherein an electronic patient monitor is connected to a bed mat.

[0021] Figure **2** illustrates the general environment of the instant invention, wherein an electronic patient monitor is connected to a chair mat.

[0022] Figure **3** contains an illustration of the main features of a preferred embodiment of the instant pressure sensitive mat.

[0023] Figure **4** is an electronic schematic of the preferred pressure sensitive mat of Figure **3**.

[0024] Figure **5** contains an illustration of a preferred monitor for use with the instant invention.

[0025] Figure **6** is a schematic diagram of a preferred microprocessor-based electronic monitor for use with the instant inventive pressure sensitive mat.

[0026] Figure **7** illustrates another preferred embodiment of the instant invention, wherein the resistive ladder is configured so as to provide both a lateral and longitudinal patient position.

[0027] Figure **8** contains a schematic illustration of another preferred embodiment of the instant invention, wherein the multiple resistive ladders are provided so as to provide both a lateral and longitudinal patient position.

[0028] Figure **9** contains a schematic illustration of another preferred embodiment of the instant invention, wherein each resistive element is separately readable.

[0029] Figure **10** illustrates another preferred embodiment, wherein the number of interconnect electrical conduits has been reduced by one.

[0030] Figure **11** contains a preferred electronic monitor embodiment, wherein no microprocessor is utilized.

[0031] Figure **12** contains an optical switch embodiment suitable for use with the instant invention, wherein a foam block or similar material is used as an optical attenuator.

[0032] Figure **13** contains another preferred optical switch embodiment wherein misalignment of two optical fibers is used as an optical attenuator.

[0033] Figure **14** contains still another preferred optical switch embodiment which utilizes a movable plate or similar structure to block passing between two sections of optical fiber, thereby attenuating the amount of light passing therebetween.

[0034] Figure **15** illustrates a preferred sensor embodiment, wherein optical switches and attenuators are used instead of electrical resistors.

DETAILED DESCRIPTION OF THE INVENTION

[0035] According to a preferred aspect of the instant invention, there is provided an electronic patient monitor for use with a patient sensor, wherein the attached sensor is at least suitable for determining the location of the patient in the bed or chair through the use of a resistive ladder.

GENERAL ENVIRONMENT OF THE INVENTION

[0036] Generally speaking, electronic patient monitors of the sort discussed herein work by first sensing an initial status of a patient, and then generating a signal when that status changes (e.g., the patient changes position in the bed, the patient fails to change position in the bed, the patient leaves the bed, the sensor changes from dry to wet, the temperature of the sensor changes, etc.) or , in some cases, if the initial condition persists for too long a period of time (e.g., if the patient has not moved during a predetermined time interval). Turning now to Figure **1** wherein the general environment of one specific embodiment of the instant invention is illustrated, in a typical arrangement a pressure sensitive mat **100** sensor is placed on a bed **20** where it will lie beneath a weight-bearing portion of the reclining patient's body, usually the buttocks and / or shoulders. Generally speaking, the mat **100** / electronic monitor **50** combination works as follows. When a patient is placed atop the mat **100**, the patient's weight compresses it, thereby closing an internal electrical circuit. This circuit closure is sensed by the attached electronic patient monitor **50** and, depending on its design, this closure may signal the monitor **50** to begin monitoring the patient via the mat **100**. Additionally, in some embodiments, the monitoring phase is initiated by a manually engaged switch. Thereafter, when the patient's

status changes (e.g., if weight is removed from the sensing mat **100**, thereby breaking the electrical circuit, or if the patient changes position on the mat **100**) this change is sensed by the attached electronic patient monitor **50** which responds to the changing condition according to its internal design and/or programming.

[0037] In some configurations, the changed circumstance of the patient will result in a signal or alarm being sent to notify a caregiver of the event. For example, if the patient has risen to his or her feet and left the bed, an electronic signal will be sent to a remote nurses / caregivers station via electronic communications line **60**. In other arrangements, and more pertinent to the instant disclosure, if the patient's circumstance does not change for some period of time (e.g., if the patient has remained motionless within the bed or chair) an alarm will be sounded. In still other arrangements, an alarm might be sounded if, for example, the patient's skin temperature rises, which can in some instances be a precursor to the formation of a decubitus ulcer. Note that additional electronic connections not pictured in this figure might include a monitor power cord to provide a source of AC power although, as generally pictured in this figure, the monitor **50** can certainly be configured to be either battery or AC powered. In other configurations, if the monitor **50** is designed to track the patient's position in the bed, a change in position would not necessarily result in an alarm being generated, but rather such a change might be recorded by the monitor **50** for later review and analysis by the staff or for purposes of monitoring the patient's movement history as is discussed at greater length hereinafter. Similarly, if the patient has not moved for some predetermined period of time, that circumstance could also generate an alarm. Those of ordinary skill in the art will recognize

that the previous examples are just a few of the many variations of this general scheme that are possible.

[0038] In another common arrangement, and as is illustrated in Figure **2**, a pressure sensitive chair sensor **200** might be placed in the seat of a wheel chair or the like for purposes of monitoring a patient seated therein. As has been described previously, a typical configuration utilizes a pressure sensitive mat **200** that is connected to an electronic chair monitor **250** that is suspended from the chair **30**. Because it is anticipated that the patient so monitored might choose to be at least somewhat mobile, the monitor **250** will usually be battery powered and will signal a patient change event (or, patient non-change event) via an internal speaker, rather than a hardwired nurse-call. Of course, those of ordinary skill in the art will understand that in some instances the monitor **250** can be configured to communicate wirelessly with the nurses' station through RF, IR, ultrasonic or other communications technology.

PREFERRED EMBODIMENTS

[0039] In accordance with a first aspect of the instant invention and as is generally shown in Figure **3A**, there is provided a patient sensor **300** which is designed to determine at least an approximate longitudinal position of the patient on the sensor and, additionally, to determine an occluded length of the sensor.

[0040] In a first preferred arrangement, a mat-type sensor with a resistive (or similar component) ladder which is comprised of a plurality of resistive elements arrayed in a spaced apart configuration is used to determinate at least a longitudinal position of the patient on the sensor. As is illustrated in Figure **3B**, the preferred mat **300** is comprised of

three layers: upper **350** and lower **360** non-conductive layers, and inner spacer **355** which is positioned between and separates the upper **350** and lower **360** layers.

[0041] In a preferred arrangement, the pressure sensitive mat of the instant invention is generally rectangular in shape and provides external electrical connectivity by way of electrical line **305** and connector **308**. Preferably the connector **308** will take the form of an RJ-11 or similar connector. As is best illustrated in Figure **3B**, the preferred sensor **300** is comprised of a "sandwich" of three layers: two outer nonconductive layers **350** and **360**, and, preferably, an inner nonconductive central spacer **355**. In the preferred embodiment, each of these layers is made of a flexible material such as polyester. Additionally, it has been contemplated by the inventors that polyethylene layers might be bonded to each of these of the components **350**, **355**, and **360** to make it possible to fuse them together as a single unit by, for example, heat sealing, or, alternatively, by pressure sensitive adhesive.

[0042] Preferably, the inner surface of upper member **350** will contain a screened or printed pattern of electrically conductive material such as silver-based ink or, alternatively, carbon ink black, etc., which renders portions of that surface electrically conductive. In a preferred arrangement, the screened material is laid onto the inner surface of upper member **350** in such a way that at least two different electrically isolated circuits are created. In Figure **3B**, a first circuit **335** is created which is preferably accessible via either connector **320** or **325**. Preferably, contact circuit **335** will contain a plurality of cross members **338** which are interleaved with the corresponding cross members **333** from circuit **323**. As can be seen, one preferred optional feature of this circuit is that it by measuring the resistance from connector **320** to connector **325** it is possible to determine

the actual value of the single resistive element **331** (i.e., to determine the actual resistance of the "calibration resistor"). In a preferred embodiment, the calibration resistive element **331** will be sized to have the same value as the sensing elements **330**, although those of ordinary skill in the art will recognize that this is not essential. A principal reason for including such a separate resistive element circuit is that it permits the instant invention to accommodate manufacturing variations that might occur in printing the conductive portions of the mat **300**. That is, in the preferred arrangement the resistive elements **330** and **331** will formed of conductive ink and will be printed onto the nonconductive layer **350**. Although this method of creating the circuits **323** and **335** is very cost effective, batch variations in ink thickness, conductivity, etc., can cause each of the resistive elements to be different in value than was called for in the specification. Obviously, to the extent that this variation is relatively large and not otherwise accounted for, the determination of the patient's position on the sensor could be made unreliable. One method of potentially reducing this inaccuracy is by individually recalibrating each of the resistors each time the mat is used (e.g., by having the caregiver successively individually activate each of the switches **410** through **470**) at the direction of the CPU. A more efficient alternative, however, is to separately measure the resistive value of calibration element **331**, and provided that any manufacturing variation that might be present in resistive elements **330** is comparably present in calibration element **331**, modify the calculations that are described hereinafter according to methods well known to those of ordinary skill in the art to account for less than perfect manufacturing. For example, if the resistance of the calibration element **331** is expected to be 100 ohms, and the actual measurement gives 90 ohms, then it is straightforward to adjust the calculations that

produce the patient's location to reflect this variation (e.g., by simply scaling all measured resistances by the factor 100/90). Finally, note that another way of calibrating the preferred resistive ladder is by putting a constant current into connector **310** while no patient is present and reading the resulting voltage at **310** while grounding **315**. Assuming for purposes of illustration that all of the resistive elements **330** have the same nominal value, this reading will make it possible to determine the total number of resistors in the system, as well as the actual total resistivity. To the extent the measured resistivity differs from the nominal resistivity, subsequent readings can be adjusted proportionally.

[0043] Circuit **333** is preferably accessible by both connector **310** and connector **315**. As was mentioned previously, this circuit preferably has a plurality of cross members **333** which are interleaved with, but electrically isolated from, cross members **338** of contact circuit **335**. Additionally, circuit **333** contains a plurality of identical resistive elements **330** which are connected in series. By measuring the resistance across connectors **310** and **315** it is possible to measure the total resistance in the circuit **333**.

[0044] Central spacer **355** is preferably made of a flexible and resilient material such as polyester and contains a plurality of apertures **340** therethrough. The location of each aperture **340** should at least approximately coincide with the interleaved cross members **333** and **338** when the surfaces **350**, **355**, and **360** are assembled into the single sensor **300**.

[0045] Upper member **360** preferably contains a plurality of conductive elements **380**, which at least partially span the apertures **340**. In the preferred embodiment, conductive elements **380** are configured such that when weight is placed on the mat **300**, that pressure will force the conductive elements **380** through one or more apertures **340**

and into contact with circuits **323** and **335**. More particularly, conductive elements **380** are configured such that when they come into contact with cross members **333** and **338** they cause an electrical short between discrete circuits **323** and **335**. Further, and is explained in more detail below, based on the measured resistances across connectors **310, 315, 320,** and/or **325** it is possible to reconstruct the location of the patient on the mat, as well as the proportion of the mat **300** which is compressed (or, more generally, occluded) by the patient, the latter measure being indicative of the orientation of the patient on the mat **300**. Additionally, non-conductive support elements **390** are preferably superimposed upon the conductive elements **380** to help prevent inadvertent contact between the conductive elements **380** and the cross members **333** and **338** through the apertures **340** when there is no patient on the mat **300**.

[0046] In the preferred embodiment, circuits **323** and **335** are laid onto their respective non-conductive surfaces **350** and **360** by printing with a flexible conductive ink such as silver-based ink. Additionally, it is preferable for purposes of manufacturing efficiency that resistive elements **330** be formed of the same ink or other conductive material as is used to create the circuits **323** and **335**. As those of ordinary skill in the art will understand, resistive elements **330** can readily be formed to match a desired resistive value by simply adding length to the path traveled by electricity in completing the circuit. Because the conductive material has an inherent resistance, adding length to the path correspondingly increases the resistance of the circuit. As a consequence, in the preferred embodiment the resistive elements **330** are formed by printing additional lengths of the same conductive material used elsewhere in circuits **323** and **335**. One obvious advantage of this approach is that it is more cost effective to print all of the elements of the mat in a

single pass. Additionally, if a discrete resistor were to be used that element could very well introduce a hard bump or bulge in the mat surface, which might prove to be uncomfortable for the patient resting thereon. That being said, those of ordinary skill in the art will recognize that there are many ways that resistive or other elements suitable for use with the instant invention could be introduced into the circuits **323** and **335**.

[0047] Turning now to Figure **4**, this figure contains a schematic illustration of a preferred embodiment of the circuits of Figure **3**. As can be seen, the closure of switches **410**, **420**, **430**, **440**, **450**, **460** and/or **470** engage different numbers of resistive elements **330**. This arrangement allows the attached electronic monitor to determine at least approximately the position of the patient on the sensor **300** and the number of switches (**410** to **460**) that have been closed by the patient's weight, this latter count being representative of the patient's position on the mat.

[0048] According to a preferred arrangement, given the circuit configuration of Figure **4**, it is possible to determine the position and orientation of the patient on the mat according to the following preferred scheme. First, as an initial calibrating measurement and as has been described previously, it is preferred that the resistance between connectors **325** and **320** be measured and, assuming that any significant variation in ink quality or quantity has affected every resistive element **330** in the same general fashion, this measurement can be used to determine the approximate resistance of a single resistive element in the circuit which then provides a correction factor that can be applied in subsequent calculations.

[0049] Continuing with the discussion of Figure **4**, note that by measuring the resistance (or alternatively the voltage or any other similar quantity) between leads **315** and

320 an estimate of the patient's position on the mat may be determined (circuit "C1" hereinafter). More specifically, the measured resistance will be indicative of the nearest switch (**410** through **460**) to the connector-end that is engaged. By way of example, and assuming for purposes of illustration only that each resistive element **330** is the same value, if contacts **440** and **450** are both engaged, the measured resistance between **315** and **320** will be approximately three times the resistance of individual resistor **330**. Obviously, the calculated resistive value across these contacts will vary depending on the precise combination of contacts that are engaged and the values of the resistances. Further, it is readily possible to build a table or develop an equation that relates the measured resistance to every possible position of the patient on the mat **300**. For example, Table 1, which follows, contains a listing of voltages normalized to 1 volt that would be measured across the leads indicated as a function of the number and location of switches engaged. Note that in the preferred embodiment, the resistive elements **330** are resistors and the preferred normalized resistance of each is about 100 ohms, with the values in column C1 below being normalized to 1 volt.

Table 1: Fractional Voltage Arising from Different Combinations of Closed Switches **410** to **470**

Row	410	420	430	440	450	460	470	C1	Fraction	C2	Fraction
1	•							0.875	7/8	0.875	7/8
2		•						0.750	6/8	0.857	6/7
3			•					0.625	5/8	0.833	5/6
4				•				0.500	4/8	0.800	4/5
5					•			0.375	3/8	0.750	3/4
6						•		0.250	2/8	0.667	2/3

Row	410	420	430	440	450	460	470	C1	Fraction	C2	Fraction
7							•	0.125	1/8	0.500	1/2
8	•	•						0.857	6/7	0.857	6/7
9		•	•					0.714	5/7	0.833	5/6
10			•	•				0.571	4/7	0.800	4/5
11				•	•			0.429	3/7	0.750	3/4
12					•	•		0.286	2/7	0.667	2/3
13						•	•	0.143	1/7	0.500	1/2
14	•	•	•					0.833	5/6	0.833	5/6
15		•	•	•				0.667	4/6	0.800	4/5
16			•	•	•			0.500	3/6	0.750	3/4
17				•	•	•		0.333	2/6	0.667	2/3
18					•	•	•	0.167	1/6	0.500	1/2
19	•	•	•	•				0.800	4/5	0.800	4/5
20		•	•	•	•			0.600	3/5	0.750	3/4
21			•	•	•	•		0.400	2/5	0.667	2/3
22				•	•	•	•	0.200	1/5	0.500	1/2
23	•	•	•	•	•			0.750	3/4	0.750	3/4
24		•	•	•	•	•		0.500	2/4	0.667	2/3
25			•	•	•	•	•	0.250	1/4	0.500	1/2
26	•	•	•	•	•	•		0.667	2/3	0.667	2/3
27		•	•	•	•	•	•	0.333	1/3	0.500	1/2
28	•	•	•	•	•	•	•	0.500	1/2	0.500	1/2

By way of explanation, the column labeled "C1" contains resistances measured across contacts **315** and **320** with voltage applied to **310** and with **315** being grounded with switches **410** through **470** closed as indicated. The values stored in the column labeled "C2" are the resistances measured across contacts **315** and **320** with voltage applied to **325** and with **315** being grounded with switches **410** through **470** closed as indicated. Finally,

each cell that contains a bullet therein indicates that the corresponding switch **410** through **470** is closed.

[0050] Note that in some instances it is necessary to measure both circuits to uniquely determine the location and number of switches compressed. For example, the normalized voltage that would be observed when only switch **420** is closed (0.75, Row 2) is the same as would be observed if switches **410** through **450** were closed (0.75, Row 23). In such an instance, reference to the second circuit C2 (contacts **315** and **320**) makes it possible to automatically differentiate between these two cases, as the C2 normalized voltages for these two conditions are 0.857 and 0.750 respectively.

[0051] Additionally, given the preferred arrangement of the instant invention, it is also readily possible to determine using the total number of switches/contacts that the patient's weight has closed. Those of ordinary skill in the art will recognize that the resistance between contacts **315** and **320** provides such a measure, preferably when used in concert with the "nearest switch" calculation developed above (circuit "C2", hereinafter). As a specific example, consider the case where the patient's weight has forced switches **440** and **450** into contact. The previous calculation has will have determined that at least switch **450** (the nearest) has been engaged. Given this information together with the results from Table 1, it is possible to determine how many contiguous switches have been closed by the patient's weight on the mat.

[0052] Of course, a principal reason for acquiring this information is so that it can be determined whether or not a patient has exhibited sufficient activity to skip the next scheduled assisted "turn". That is, in a typical arrangement a physician will prescribe that a patient be manually turned at some predetermined time interval, e.g., every two hours, so

that the patient does not rest for too long a period of time in one position. As has been described previously, assisted turning is disruptive to the patient and taxing on the staff and, to the extent that the patient has already moved himself or herself, it may be that the next scheduled turn may and should be skipped.

[0053] However, those of ordinary skill in the art will recognize that not every movement by a patient is sufficient to reoxygenate the tissues that have been compressed by the patient's weight. For example, if a patient is resting on his or her right side and moves laterally across the bed without changing orientation, such a simple relocation would not relieve pressure from the compressed tissue and, as a consequence, the patient would likely still need to be manually turned.

[0054] Thus, it is preferred by the instant inventors that the location information which is obtained from the mat **300** be combined with logic (whether implemented by discrete logic, one or more gate arrays, analog circuitry, or via a CPU / software combination, etc.) to help determine whether or not the patient has moved significantly, where a significant move is one that persists at least long enough for there to be sufficient reoxygenation of the previously compressed tissues.

[0055] According to another preferred embodiment, there is provided an invention substantially as described above, but wherein the number of switch closures is determined by preferably applying a constant current to connector **320** while grounding either **310** or **315** and measuring the resulting voltage. Table 2 which follows illustrates how various switch closures will be reflected in the measured voltages.

Table 2: Fractional Current Arising from Different Combinations of Closed Switches **410** to **470**

Row	410	420	430	440	450	460	470	C3 Volts	C3*	C4 Volts	C4**
1	•***							2.9167	7	0.4167	1
2		•						2.5000	6	0.8333	2
3			•					2.0833	5	1.2500	3
4				•				1.667	4	1.667	4
5					•			1.2500	3	2.0833	5
6						•		0.8333	2	2.5000	6
7							•	0.4167	1	2.9167	7
8	•	•						2.5000	6	0.4167	1
9		•	•					2.0833	5	0.8333	2
10			•	•				1.667	4	1.2500	3
11				•	•			1.2500	3	1.667	4
12					•	•		0.8333	2	2.0833	5
13						•	•	0.4167	1	2.5000	6
14	•	•	•					2.0833	5	0.4167	1
15		•	•	•				1.667	4	0.8333	2
16			•	•	•			1.2500	3	1.2500	3
17				•	•	•		0.8333	2	1.667	4
18					•	•	•	0.4167	1	2.0833	5
19	•	•	•	•				1.667	4	0.4167	1
20		•	•	•	•			1.2500	3	0.8333	2
21			•	•	•	•		0.8333	2	1.2500	3
22				•	•	•	•	0.4167	1	1.667	4
23	•	•	•	•	•			1.2500	3	0.4167	1
24		•	•	•	•	•		0.8333	2	0.8333	2
25			•	•	•	•	•	0.4167	1	1.2500	3
26	•	•	•	•	•	•		0.8333	2	0.4167	1
27		•	•	•	•	•	•	0.4167	1	0.8333	2
28	•	•	•	•	•	•	•	0.4167	1	0.4167	1

By way of explanation, the values in the column headed by "C3 Volts" are the voltages read between **320** and **315** with a constant current, for example 4.167 mA, being applied to **320**. Switches **410** through **470** are closed if a bullet is present in the corresponding column. The values stored in the column labeled "C4 Volts" are the voltages read between **320** and **310** with a constant voltage applied to **320**, and with switches **410** through **470** being closed as indicated. If, for instance, each resistor **330** has been chosen to be 100 ohms, the voltage drop across each is 0.4167 volts. Thus, the number of resistors in the circuit may be calculated (assuming a given number of switch closures) and the results of such a calculation may be found in the columns in the Table 2 labeled C3 and C4. Note that each cell in the previous table that contains a bullet therein indicates that the corresponding switch **410** through **470** is taken to be closed. The values in the column headed by "C3" are the number of resistors read between **320** and **315** while a constant current is applied to **320** with switches **410** through **470** being closed as indicated. The values stored in the column labeled "C4" are the number of resistors read between **320** and **310** with a constant voltage being applied to **320** and with switches **410** through **470** being closed as indicated.

[0056] As should be clear in be reference to the previous table, by monitoring the measured voltage of the instant preferred sensor along two different paths, it is readily possible to determine which of the switches **410** through **470** are closed either individually or in combination. Note that the method of determining patient location with this embodiment is analogous to that discussed previously in the case where voltage application was utilized.

[0057] In practice and as is generally illustrated in Figures **5**, **6**, and **11**, the instant invention would be used as follows. As a first step, the sensor **300** would be placed into electronic communication with an electronic patient monitor **500**. Typically, such a monitor **500** will contain an interface port **520** which preferably takes the form of a standard connector (e.g., an RJ-11-type connector) into which the sensor cord **305** is plugged. Within the monitor **500** will preferably be found a microprocessor **620** which might additionally utilize a separate timer / clock chip **640** to assist it in measuring the various time intervals that are useful and necessary in the monitoring of an at-risk patient. Of course, those of ordinary skill in the art will recognize that a separate (or external) clock chip **640** is not strictly necessary and, instead, software timing loops could readily be used instead. Finally, it is customary to include some amount of computer RAM/ROM **610** in which to store program instructions and variable values. That being said, those of ordinary skill in the art will recognize that such RAM/ROM **610** need not be external to the microprocessor **602** but might, instead, be incorporated into the microprocessor **602** according to methods well known to those of ordinary skill in the art.

[0058] Although the previous monitor embodiment **500** was microprocessor-based, those of ordinary skill in the art will recognize that the simple functionality that is minimally required of this monitor could readily be implemented with discrete logic components. As is generally suggested in Figure **11**, sensor port **1110** could be monitored by detector **1120** which might be comprised of, by way of example only, a position detection circuit, a window comparator, a sample-and-hold circuit, and a differential amplifier circuit. The detector circuit **1120** would preferably work in combination with one or more timers **1130**, which timers would preferably include a timer for monitoring the

doctor-prescribed turn interval (e.g., a two-hour timer) and a separate timer to determine whether the patient has maintained a changed position for a period of time sufficient to allow reoxygenation of the previously-compressed tissues (e.g., a ten-minute timer). Finally, if the alarm conditions are satisfied, an alarm circuit **1140** would be triggered which preferably would sound an audible alarm via speaker **1150** which might be directly incorporated into the patient monitor **1100** or situated remotely thereto, e.g., at a nurses station.

[0059] After the patient has been placed on the sensor **300** and the monitor **500** has been initialized, a determination of the patient's location and an estimate of his or her orientation will be made. The orientation will preferably be established by reference to the percentage of the mat **300** that is occluded. That is, if only a few (e.g., one or two) of the switches **410** through **470** are closed, the patient is likely lying on his or her side. However, if a larger number are closed (e.g., 3 or 4 or more), the patient is likely lying on his or her back or stomach. Of course, those of ordinary skill in the art will recognize that it is not the number of switches that are closed that is determinative of the patient orientation, but rather the proportion of the switches that are closed when compared with the total number of switches, such a proportion being a measure of the length of the contact area between the patient and the sensor **300**.

[0060] Thereafter, the monitor **500** will continue to monitor the patient's location and orientation to determine whether or not the patient has moved. However, and as is well known to those of ordinary skill in the art, determining whether or not the patient has "moved" is not enough: the patient who is lying, say, on his right side and who moves sideways in the bed is still in risk of decubitus ulcers. Thus, by analyzing the location of

the patient together with the number of switches engaged it will be possible to tell at least approximately whether the patient has truly moved to so that manual turning will not be necessary. For example, if the patient's weight has caused only two of the switches **410-460** to be engaged, that patient is likely lying on his or her side. However, if the weight distribution of the patient later changes to engage four of the switches **410-460**, it is likely that the patient has rolled onto his or her back or stomach. Thus, the patient is unlikely to need to be manually turned.

[0061] In a typical arrangement, the patient will be monitored continuously by an attached electronic patient monitor during the time that he or she is bed-fast or chair-fast. Usually, the attending physician will prescribe a turn interval for the patient, the turn interval being the frequency with which the staff must manually turn the patient so that the compressed tissues can reoxygenate. A two-hour turn interval is commonly used. A preferred embodiment of the instant invention operates by determining an initial orientation of the patient on the sensor and then thereafter repeatedly redetermining the patient's position over time to ascertain whether or not he or she has moved. Those of ordinary skill in the art will understand that there is no set sampling frequency or period of time between measurements of the patient's position that need be used, but that the sampling interval must necessarily be shorter than the turn interval and, preferably, will be on the order of once a minute or so. Further, there is no requirement that the successive checks of the patient's position be equally spaced in time, although that is also preferred. Thus, when the period of time between successive patient measurements is alluded to herein, that time period should be understood to be shorter than the patient's turn interval and otherwise could be arbitrarily closely spaced in time.

[0062] In another preferred embodiment of the instant invention, there is provided a sensor substantially as described above, but wherein a plurality of spaced-apart longitudinally aligned resistive ladders are utilized so as to give a horizontal and vertical profile of the patient's orientation in the bed, i.e., to provide both a longitudinal and vertical measurement of the patient's location. As is generally indicated in Figure **7**, in a preferred arrangement the resistive ladder of Figures **3** and **4** is spatially configured so as to give an approximate "X" and "Y" location of the patient on the sensor **700**, where "X" is preferably measured with respect to the width of the bed and the "Y" with respect to its length. As is best illustrated in Figure **7**, by spatially varying the location of the resistive elements **330** and the switches **410 – 470**, it is possible estimate, not only the lateral location of the patient on the mat, but also his or her vertical position relative to the head (or foot) of the bed. In more particular, consider the case where switches **440**, and **460** are closed ("Case 1") in comparison with the case where, say, switches **450**, and **470** are closed ("Case 2"). Generally speaking, the combination of switches in Case 1 would be interpreted as a patient who is higher (i.e., closer to the head) of the bed than the combination of Case 2. Thus, it should be clear that the preferred arrangement — which utilizes a series of staggered switches — can be used to obtain general information about the vertical location of the patient in the bed.

[0063] However, note that, in addition to giving an approximate "X" and "Y" position of the patient in the bed as has been discussed previously, the instant sensor **700** can provide dynamic / real-time information about the patient's condition by monitoring the changing closure patterns of its switches over time. For example, in the previous scenario where the closure pattern of Case 1 is followed directly by the pattern of Case 2,

the patient is likely sliding toward the foot of the bed. Further, and in another preferred embodiment, this information will be utilized to estimate the amount of shear experienced by the patient's tissue during this time period.

[0064] Thus, in another preferred arrangement, there is provided a sensor and attached electronic patient monitor substantially as described above, but wherein the patient monitor utilizes information from the time-varying switch closures to help identify those patient's that are at risk of decubitus ulcers by virtue of shear stress placed on their tissues, a sheer stress being a force that is tangent to the skin's surface. As is well known to those of ordinary skill in the art, the amount of shear experienced by a patient is increasingly recognized as another factor in predicting the occurrence of decubitus ulcers. A patient's sliding down in the bed is an obvious source of such stress, and may, indeed, cut off oxygenated blood to the patient's tissues by capillary deformation, thereby increasing the risk of injury. If an at-risk patient can be automatically identified and the staff notified, additional manual intervention, or a change to another bed or chair, might circumvent the occurrence of ulcer formation entirely. Needless to say, it is much better to prevent decubitus ulcers than to treat them. Additionally, shear that is caused by sliding can indicate a general restlessness in the patient, which might be correlated with an increase in his or her pain or anxiety level. Those of ordinary skill in the art will recognize the utility of being able to automatically identify such a change in patient condition and to notify the staff so that intervention is possible if it is necessary.

[0065] According to another preferred embodiment, there is provided a mat substantially as described above, but wherein there are two or more resistive ladders configured in a roughly parallel arrangement. As is generally indicated in Figure **8**, in a

preferred arrangement two or more electrically isolated resistive ladders are utilized, each such ladder being independently accessible via connectors **810** through **825** and **830** through **845**, respectively. As should be clear by reference to this figure, switches **850** through **862** are separately readable to determine which are closed. These switches, in combination with switches **864** through **876** provide a horizontal, as well as a vertical, image of the patient's position. Given this sort of arrangement, it is possible to determine vertical and horizontal changes in the patient's position and, if desired, to estimate whether or not the patient's body is experiencing shear. As a specific example of how the presence of shear might be sensed, if the contract area (occluded region) of the mat remains constant, but the vertical (i.e., "Y") location of the patient indicates the he or she has moved down in the bed, the patient is likely being exposed to shear and the staff should be notified of this problem. Needless to say, there could be many more such parallel arrays of resistive elements than the two arrays that are illustrated in the embodiment of Figure **8**.

[0066] According to still another preferred embodiment, there is provided a patient sensor substantially as described above, but wherein each resistive element is made part of a separate circuit that is individual readable by the microprocessor **620**. That is, and as is generally indicated in Figure **9**, in a preferred arrangement each switch **910** through **924** is separately readable by virtue of the individual electrical lines coming to it. That is, rather than using a four-element electrical line **305**, a nine-element line is preferably used instead, wherein each of the conductive elements leading to switches **910** through **924** is kept electrically isolated from the others. This means that a patient monitor in electrical communication with the embodiment of Figure **9** can directly determine which of the switches is closed, e.g., by bringing each connecting line into a separate port in the

microprocessor (or other programmable device) of the monitor. Note that in this case, the resistive elements **330** might take any resistive value that is greater than or equal to zero. Finally, note that although the switches in Figure **9** and elsewhere in this disclosure are normally opened, those of ordinary skill in the art will recognize that normally closed switches could be used instead and that the procedure for determining patient location discussed previously would not need to modified materially in order to determine the patient's position.

[0067] Additionally, it should be noted in connection with Figures **4** and **9** that it would be readily possible to create switches that are based on optical, rather than electrical, properties, wherein the resistive element takes the form of an optical attenuator. That is, if the electrical conductor **930** were instead replaced by some sort of optical fiber, if resistive elements **330** included sections of optical fiber, and, if, for example, the amplitude or frequency of light passing through the switch were changed (e.g., attenuated or amplified) when the patient were present on the sensor, closure of the switches **910 – 924** could be determined by, for example, monitoring the amplitude of light received through lead **940**.

[0068] Figure **12** illustrates a first preferred optical switch that would be suitable for use with an optical embodiment of the instant invention. In this embodiment a block of open cell foam or similar material acts as the optical attenuator. By way of explanation, a light source **1210** is provided at one end of an optical conduit **1220** (e.g., a section of fiber optic cable). Light is transmitted through the optically conductive material **1220** until it reaches optical attenuator **1230**, which in one preferred embodiment is a low density open cell foam. A portion of the light that falls on the attenuator **1230** will be transmitted therethrough to optical conduit **1240** (e.g., a section of fiber optic cable) where it will be

further conducted to photo-sensor **1250**. As is well know to those of ordinary skill in the art, when open cell foam is compressed (e.g., via the weight of the patient on the sensor) its density increases and it becomes less transparent to light. Thus, by measuring the intensity of light that is received at photo-sensor **1250** it will be possible to determine whether or not the foam block is compressed and, hence, which of the switches within the sensor are "closed". In a preferred arrangement, an initially calibrated amount of light that is transmitted through the attenuator **1230** when the foam is not compressed will be continuously compared with the actual amount of light received from light source **1210**.

[0069] According to a second preferred optical switch embodiment, and as is generally illustrated in Figures **13A** and **13B**, there is provided an optical attenuator which utilizes misalignment of two optical conduits as a means of attenuating the optical signal when the patient is present on the sensor. When the patient is not present on the sensor (Figure **13A**) the ends of optical conduits **1320** and **1340** will be in near direct alignment and much of the light that emanates from the source conduit **1320** will be received by receiver conduit **1340**, depending, of course, on the distance between the two conduits. The patient's weight on the sensor, which is typically made to be at least somewhat flexible for purposes of the increasing the patient's comfort, would tend to misalign the two optical conduits (Figure **13B**) and reduce the amount of light transmitted between them. A photo-sensor **1250** in optical communication with the receiving conduit **1340** would thus be readily able to determine whether or not the switch was engaged depending on the level of light received. Preferably, a reference level of light transmissivity will be established while the mat is empty so that deviations therefrom can be identified. The optical attenuation in this case is brought about by the degree of physical misalignment

between the sections of optical conduit. Preferably a calibration value will be provided against which the currently measured optical intensity will be measured which will then provide an indication of when the termini of the two conduits **1320** and **1340** are in alignment. Pressure on the sensor (which is typically made to be at least somewhat flexible for purposes of increasing the patient's comfort) will force the two conduits into at least partial misalignment, thereby reducing the amount of light transmitted therebetween (Figure **13B**). Thus, by monitoring the quantity of light received through a plurality of such optical switches it is possible to determine the patient's position location on the sensor and the amount of the sensor that is occluded which is, of course, correlated with the patient's orientation. .

[0070] In still another preferred optical switch embodiment and as is generally indicated in Figure **14**, there is provided an optical switch suitable for use with the instant invention, wherein a shutter **1430** moves downward under the pressure of the patient's weight to block the transmission of light between source conduit **1220** and receiver conduit **1240**. Clearly, placing a photo sensor **1250** in optical communication with receiver conduit **1240** would make it possible to determine whether or not the subject switch were open and, hence, whether the patient were present on the sensor.

[0071] As a final example of an optical embodiment of the instant invention, there is provided in Figure **15** a preferred arrangement wherein a plurality of optical attenuators **1530** (e.g., any of the attenuators of Figures **12** to **14**, but the embodiment of Figure **14** would likely be best suited) are placed in series with light collectors **1540** - **1570** interspersed in between. Preferably and for purposes of the instant embodiment, the light originating from all of the light collectors **1540** - **1570** will be additively combined

through junction **1595** into a single optical conduit where it can be read by photo-sensor **1250**. For purposes of illustration only, the attenuators will be assumed to be the shutters **1430** of Figure **14**. According to one preferred embodiment, light sources **1510** and **1520** will be positioned at opposite ends of the light conduit **1590** and alternately activated. That is, light source **1510** will be activated while source **1520** is dark, and then light source **1510** will be darkened while source **1520** is activated. The reason for this arrangement is that it allows a patient's location and occlusion to be readily determined using a single photo-sensor **1250**. If, for example, optical attenuators **1532 – 1535** are engaged (i.e., the shutters of these optical attenuators are in the "down" or blocking position) light from source **1510** will be received only at collector **1540**, with the remaining collectors **1545 - 1570** being dark. However, when optical source **1520** is activated, light will be received at collectors **1560** through **1570**, with the remaining collectors being dark (i.e., **1540** through **1555**) being dark. Given this information, it is possible to determine the number of switches open (or engaged) on the left and on the right and, thus, the position and amount of occlusion of the sensor by the patient. Note that in many ways the operation of the optical embodiment of Figure **15** is analogous to the operation of the electrical embodiment of Figure **4**. Finally, note that, if desired a calibration optical attenuator **1539** could added so that, by reading the amount of light transmitted therethrough and comparing the observed value with the presumably known nominal value for this element, a correction factor could be established that could be applied to the other attenuators **1531 - 1538**.

[0072] Note that if a microprocessor is utilized as a component of the monitor **500**, the only requirement that such a component must satisfy is that it must minimally be an

active device, i.e., one that is programmable in some sense, that it is capable of recognizing signals from a bed mat or similar patient sensing device, and that it is capable of initiating the sounding of one or more alarm sounds in response thereto. Of course, these sorts of modest requirements may be satisfied by any number of programmable logic devices ("PLD") including, without limitation, gate arrays, FPGA's (i.e., field programmable gate arrays), CPLD's (i.e., complex PLD's), EPLD's (i.e., erasable PLD's), SPLD's (i.e., simple PLD's), PAL's (programmable array logic), FPLA's (i.e., field programmable logic array), FPLS (i.e., fuse programmable logic sequencers), GAL (i.e., generic array logic), PLA (i.e., programmable logic array), FPAA (i.e., field programmable analog array), PsoC (i.e., programmable system-on-chip), SoC (i.e., system-on-chip), CsoC (i.e., configurable system-on-chip), ASIC (i.e., application specific integrated chip), etc., as those acronyms and their associated devices are known and used in the art. Further, those of ordinary skill in the art will recognize that many of these sorts of devices contain microprocessors integral thereto. Thus, for purposes of the instant disclosure the terms "processor," "microprocessor" and "CPU" (i.e., central processing unit) should be interpreted to take the broadest possible meaning herein, and such meaning is intended to include any PLD or other programmable device of the general sort described above.

[0073] Additionally, in those embodiments taught herein that utilize a clock or timer or similar timing circuitry, those of ordinary skill in the art will understand that such functionality might be provided through the use of a separate dedicate clock circuit or implemented in software within the microprocessor. It might further be obtained with discrete, linear, timers and logic circuitry: a microprocessor is not strictly required, but is

merely convenient. Thus, when "clock" or "time circuit" is used herein, it should be used in its broadest sense to include both software and hardware timer implementations.

[0074] Finally, and according to still another preferred embodiment, there is provided a patient sensor substantially similar to that disclosed previously, but wherein the number of connecting electrical leads has been reduced. As is illustrated generally in Figure **10**, those of ordinary skill in the art will recognize that by using diodes **1005** it is possible to eliminate connectors **310** and **315** and replace them with a single electrical lead **1010**. That being said, it should be noted that, in reality, the number of connectors has not been reduced but rather only the number of interconnects. As a consequence, for purposes of the instant disclosure and the claims that follow, when it is noted that three conductors are required, that language should not be limited to those cases where three discrete interconnects are utilized, but rather should be understood in the broader sense to mean any configuration of conductors and connectors that is adequate to allow an attached electronic patient monitor to determine the number of switch closures when a patient is present on the sensor.

CONCLUSIONS

[0075] Although the preferred embodiment of the instant invention utilizes a ladder of electrical resistors to determine the position of the patient on the sensor, it should be clear to those of ordinary skill in the art that capacitive or inductive elements, some combination of same, semiconductors (e.g., forward biased diodes or zener diodes), temperature sensors (e.g., thermocouples), piezoelectric elements, etc. could readily be used instead. Of course, rather than measuring the resistance across leads **310** through

325 it would be possible to measure the resonance time constant (RC or LC time constant) or some other quantity representative of the number of circuits that are closed in the mat. In fact, the instant invention could also be configured to operate by calculating the various travel times of an electronic pulse that is sent through the instant circuitry (e.g., as measured by a Ditmico tester). Note that, in the preferred embodiment, the resistive elements **330** are preferably created by screening additional lengths of the electrically conductive material onto the mat surface, thereby creating increased resistance. This additional length would also result in an increased travel time as well, so a technique that measured the travel time of an electronic pulse from, say, **320** to **310** and from **315** to **320** would be able to determine the number of switches closed by the patient's weight. Thus, as used herein, when the term "resistive value" is used to describe the measurement of some electrical property of the circuit, it should be understood that the quantity that is actually measured might be different from "resistance" and, instead, could be any other property that is representative of the number of switches that are closed in the attached mat including, without limitation, capacitance, voltage, transit time, etc. Similarly, when reference is made herein to electrical properties, electrical conductors, and electrical resistors that same language should be understood to also include optical properties, optical conductors, and optical attenuators.

[0076] Additionally, although the preferred arrangement includes an array of identical resistive elements, those of ordinary skill in the art will recognize that this arrangement is not required. It is certainly possible that some combination of different-valued resistive elements (e.g., different resistor values) might be used and, in such a

circumstance, methods similar to those discussed herein could be used to determine exactly which switches are closed when a patient is present on the device.

[0077] Those of ordinary skill in the art will recognize that the preferred embodiment, with its plurality of switches, could easily be manufactured with any number of separate switches. At the limit, of course, these switches when spaced closely together begin to approximate a continuum of contact points. Thus, it should be noted and remembered that the instant inventors have determined that the invention taught herein might be implemented in substantially the same way in the form of a single continuous resistive element. In such an embodiment, preferably the single continuous resistive element will be used with a plurality discretely spaced activation (e.g., switches **410** through **460**), the goal being to determine the nearest point of contact of the patient to one end of the mat and the occluded / contact area.

[0078] Further, note that the instant invention may be utilized to detect when a patient is moving toward the edge of the sensor with the intent of exiting the bed. It should be clear that if none of the mat switches are engaged, the patient is no longer present on the mat and, presumably, will have left the bed or chair into which he or she had been placed. Thus, the instant invention can function in connection with a conventional "exit monitor" and be used to signal the nursing staff when a patient has risen. This much should be clear. However, note that, because the preferred mat embodiment has numerous switches distributed along its length, it is possible to utilize the instant invention determine when a patient is preparing to leave the bed and, if so desired, signal that intent to the nursing staff. Note that the preferred embodiment has switches distributed throughout the length of the mat, including switches that are proximate to each end. Typically, when a patient is

intending to leave the bed, his or her weight is relocated laterally to the exit side as a prelude to exiting. Further, the speed with which the patient moves toward the edge of the bed may also be telling, with faster movements toward the bed edge usually being indicative of a patient that is preparing to exit the bed. Through the use of the instant invention, it is possible to determine when the patient's weight so-shifts by looking for instances when only the switches proximate to one end of the mat are engaged. Additionally, the velocity at which the patient moves toward the edge may also be calculated. In the event that the patient approaches the edge of the bed and / or approaches the edge of the bed in excess of a predetermined velocity, a signal will preferably be sent to the nursing staff, thereby allowing the staff to intervene before the patient has had time to stand and fall.

[0079] Additionally, although it is preferred that the instant sensor be placed under the patient's hips or back, that is not the only possible orientation. Of some additional concern is the condition of the patient's heels, elbows, and other bony prominences. Each of these sites can potentially be a site at which decubitus ulcers can develop. Although the sensor of the instant invention could certainly be positioned under any of these areas and/or multiple sensors could be used (e.g., one under each area of concern), more practically speaking the those of ordinary skill in the art will recognize that monitoring the patient's movement at his or her hips allows at least some general inferences about the other locations of concern (e.g., if the patient has rolled on his or her side it is likely that the heels are in a position to reoxygenate, etc.)

[0080] Further, it should be noted and remembered that, although a preferred embodiment of the instant invention employs a discrete central spacer, that is not

absolutely required. That is, it is certainly possible that the role of the "spacer" could be filled by a series of noncontiguous nonconductive "dots" or other discrete shapes that have been imprinted across the conductive elements **380** (e.g. the support elements **390**). Thus, for purposes of the instant invention, the terms "spacer" and "central spacer" should be broadly interpreted to include any structure that serves to separate the upper **350** and lower **360** members of the instant invention when there is no weight on the mat **300**. Similarly, when the central spacer is described as having "apertures", it should be recognized that these might take the form of the embodiment of Figure **3** (i.e., holes formed within an otherwise solid central member) or they might take them form of spaces between adjacent support members (e.g., non-conductive dots), etc. In any case, a principle function of the "apertures" is to allow the upper **350** and lower **360** members to come into contact when pressure is applied to the mat and, thus, any sort of structure that permits or facilitates that operation should be considered to be an "aperture" for purposes herein.

[0081] Additionally, although it is preferable that the resistive elements **330** be screened onto the inner face of the mat **300** and thus be integrated with the mat, it should be clear that separate discrete electronic components could readily be used instead. For example, discrete resistors could be affixed to the mat **300** to serve in place of screened-on resistive elements **330**. Those of ordinary skill in the art will recognize that such an arrangement — provided that some provision were to be made so that the resistors could not be felt through the mat **300** by the patient — would function identically to the preferred embodiment discussed above.

[0082] Note further that a preferred electronic monitor of the instant invention utilizes a microprocessor with programming instructions stored therein for execution

thereby, which programming instructions define the monitor's response to the patient. Although ROM is the preferred apparatus for storing such instructions, static or dynamic RAM, flash RAM, EPROM, PROM, EEPROM, or any similar volatile or nonvolatile computer memory could be used. Further, it is not absolutely essential that the software be permanently resident within the monitor, although that is certainly preferred. It is possible that the operating software could be stored, by way of example, on a floppy disk, a magnetic disk, a magnetic tape, a magneto-optical disk, an optical disk, a CD-ROM, flash RAM card, a ROM card, a DVD disk, or loaded into the monitor over a network as needed. Additionally, those of ordinary skill in the art will recognize that the memory might be either internal to the microprocessor, or external to it, or some combination. Thus, "program memory" as that term is used herein should be interpreted in its broadest sense to include the variations listed above, as well as other variations that are well known to those of ordinary skill in the art.

[0083] Additionally, although the preferred embodiment of the instant invention utilizes a plurality of resistive elements **330** organized in a serial arrangement, alternative circuit configurations (e.g., parallel, or some other arrangement) could certainly be employed instead. All that is required for purposes of the instant invention is that the mat circuit, what ever its configuration, be capable of determining at least an occluded / contact region and a location from one end of the mat. Of course, a sensor which yielded a distance from each end of the mat would allow an immediate calculation of the occluded or contact region. Those of ordinary skill in the art will be able to devise many alternative configurations of the instant invention beyond those suggested herein.

[0084] Further, it should be noted and remembered that, although the preferred embodiment of the instant invention has the two circuits **323** and **335** and the resistive elements **330** and **331** all physically located on the same surface of mat **300**, it should be clear that various permutations of this arrangement are possible. Indeed, the only requirement is that the resistive elements **330** be in electrical communication with the circuits **323** and **325** so that the sensor **300** functions as has been described previously. Thus, it would be within the spirit of the instant invention if the resistive elements **330** were to be located, say, on the central spacer **355** or on the inner face of mat surface **360**. Similarly, the two circuits **323** and **335** need not be physically resident on the same mat element **350**, but could instead be on opposite mat elements so long as they can be selectively closed to indicate at least a patient's approximate lateral location as a function of the number of switches closed. Additionally, those of ordinary skill in the art will recognize that it is certainly possible that the sensor **300** might be made a part of, or incorporated, into the bed itself or some other structure.

[0085] Finally, it should be noted that the term "nurse call" as that term has been used herein should be interpreted to mean, not only traditional wire-based nurse call units, but more also any system for notifying a remote caregiver of the state of a patient, whether that system is wire-based or wireless (e.g., R.F., ultrasonic, IR link, etc.). Additionally, it should be clear to those of ordinary skill in the art that it may or may not be a "nurse" that monitors a patient remotely and, as such, nurse should be broadly interpreted to include any sort of caregiver, including, for example, untrained family members and friends that might be signaled by such a system.

[0086] Thus, it is apparent that there has been provided, in accordance with the invention, a patient sensor and method of operation of the sensor that fully satisfies the objects, aims and advantages set forth above. While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art and in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications and variations as fall within the spirit of the appended claims.